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ABSTRACT

A change commonly found in older persons is a general tendency for responses to external stimuli to be slowed. The document includes a review of theoretical approaches to the explanation of slowing on cognitive tasks that occur with age, and reviews the methodology of a two-part experimental study of 45 subjects. The study reports a letter-matching reaction time task to investigate the relative contributions of attentional factors, pathway effects, and motivational factors to the overall slowing seen with age. Older subjects (mean age 63.5) are found to be more accurate than younger subjects (mean age 20.0) who demonstrate greater speed but more errors. Feedback is shown to affect performance on the part of younger subjects who report pacing themselves. Statistical treatment of the data by cost benefit analysis indicates no significant difference in the time course of costs and benefits between younger and older subjects. (Author/SBP)

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Slow But Sure: A Chronometric Analysis
Of the Process of Aging

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Perhaps the most widespread change found in aging is a general tendency for responses to external stimuli to be slowed (Botwinick, 1975). At least some of this slowing may be attributable to peripheral changes that take place as a function of age (Shock, 1962). For example, spinal reflexes appear to be slowed with age (Magladery, Teasdall & Norris, 1958). Anatomical changes in the ear (Weiss, 1959) and the eye (Weale, 1963) have also been reported. The extensive literature on aging suggests, however, that not all the age-related slowing is due to either reductions in the efficiency of sensory systems or changes in the peripheral musculature.

Gaylord and Marsh (1975) have used a Shepard and Metzler (1971) mental rotation task to investigate the speed of such rotation in younger and older subjects. They find that the rate of mental rotation is slowed in their older subjects, implying a slowing of some central process. Similarly, Anders and Fozard (1973) have found that older subjects take longer per item to scan memory than younger subjects, again suggesting slowing of some central mechanism. Also in support of some sort of central slowing in older subjects is Boies' (1971) finding that differences in reaction times between physical level (i.e. "BB") and phonetic level (i.e. "Bb") letter matches are greater in the elderly. Younger subjects take about 100 msec longer to make phonetic level matches than physical level matches (Posner, 1969). Boies' sample of ten older subjects with a mean age of 50, however, showed a difference between physical and phonetic level matches of between 150 and 200 msec.

Such slowing is often thought to indicate age changes in the speed of central cognitive functions and sometimes to be evidence for a "cognitive deficit" in the aged (Brinley, 1965, p. 118). The mere finding of slowing even in central processes, however, should not necessarily be taken as evidence for a "cognitive deficit" without additional supporting evidence. For example, such changes could involve differences in the implicit value of fast versus accurate responses, relative exposure to speeded situations or other features which would not suggest a general deficit.

Four different theoretical approaches to the explanation of the slowing on cognitive tasks that occurs with age, which are neither mutually exclusive or exhaustive, are briefly reviewed below.

(1) Pathway Effects. This view suggests that the slowing due to aging takes place because the sensory-memory systems that accumulate input information are systematically deteriorating due to age. Thus regardless of the nature of the task, there will be a tendency for the information to accrue more slowly and thus at any given moment be of a lower quality in the aged than in the young. One would expect this sort of effect given the findings on slowed reflexes and changes in the eye and ear with age, as noted above. There is also some evidence that the older nervous system is "noisier" than the young one (Welford, 1958). This increase in neural noise would have the effect of decreasing the quality of the information available in the older nervous system.

(2) Attentional Effects. A second possibility is that the availability of some central attentional mechanism is decreased with age.

This might operate as though there was a chronic reduction in the level of alertness of the older subject. Several aspects of the aging data suggest such an attentional problem. For example, it is known that the time for a warning signal to produce a state of optimal alertness is longer in older subjects (Botwinick & Thompson, 1966). As the complexity of a task increases, the effects of aging also increase (Welford, 1962). It is well known that the involvement of attentional mechanisms also tends to increase with task difficulty (although this could also be consistent with hypothesis no. 1).

(3) Motivational Effects. According to this view, elderly subjects could respond rapidly but their desire to do so has been reduced. Accordingly, slowing of performance in the aged should be accompanied by increased accuracy. Most studies have not obtained sufficient error data to examine this hypothesis. However, Craik (1969) has reviewed several studies that bear on the hypothesis. These studies used a signal detection paradigm to study the effects of age. Almost all the studies found a beta change but no d' change as a function of age. Thus older subjects may be slower simply because they adopt a more conservative strategy or criterion when responding. In one particularly interesting study, Botwinick, Brinley and Robbin (1958) varied the exposure duration of two lines that subjects were to judge for length. With a relatively long duration (two seconds), older subjects took longer to respond than younger subjects. However, when the exposure duration was cut to only 150 msec reaction times for both younger and older subjects decreased but the decrease was significantly more for the older subjects. Craik concluded, "It thus

seems that old subjects prefer to take more time before deciding but that time is not necessary" (1969, p. 152). Similarly, Eysenck (1975) has found that older subjects may actually be faster at accessing information in semantic memory than younger subjects. However, the older subjects take longer to initiate their responses.

(4) Learning Effects. A view related to number 3 would hold that elderly subjects can respond quite rapidly as long as the task in question is well learned, but do not do so when the task is poorly learned. This suggests that the effects of slowing can be mitigated by over-training. High levels of training have sometimes been used to test this view (Murrell, 1970) but such studies have used very few subjects.

From the above brief review it is clear that there are several possible explanations for the general finding of slowing with age. Each explanation seems to have at least some experimental support. Because the vast majority of studies that examine slowing with age examine only one aspect of slowing, it is impossible to determine the relative contribution of the four factors noted above to the overall slowing effect. It would be desirable to have an experimental technique that would allow the contributions of the four sources of slowing to be examined separately but within the same experiment.

A letter matching task allows us to examine purely central effects on reaction time by subtracting the difference between physical (e.g. "AA") and phonetic matching (e.g. "Aa"). Use of a priming or cue signal allows separation of effects due to active attention (cost when cue is valid) from those due to pathway activation (benefit when cue is invalid).

(Posner & Snyder, 1975a, b). Purely motivational or learning explanations would probably not predict differences in any of these indicants of internal processing, while "deficit" theories would predict varying constellations of results.

Method

There was a total of 45 subjects, 28 in the age range 55-70 (mean = 63.5) and 17 in the age range 18-22 (mean = 20). The older subjects were recruited by telephone from a list of people of all ages who had responded some years earlier to a newspaper ad requesting paid volunteers for psychology experiments. The older subjects were paid $2.00 per hour for their participation. Younger subjects were taken from an introductory psychology course at the University of Oregon and received course credit for their participation.

Before reaction time testing was begun, subjects were given the digit span, vocabulary, and block design sub-tests of the WAIS. Three subjects were tested after the reaction time portion of the experiment was completed due to scheduling problems, etc.

The major portion of the experimental session was devoted to the reaction time experiment. Subjects sat, alone, in a darkened room facing a cathode ray tube (CRT). The subject's only task was to indicate, by pressing an appropriate key, whether two letters that appeared simultaneously on the CRT were the same or different regardless of whether the letters were in upper or lower case. That is, subjects were making a name match and, for example, both the pairs "AA" and "Aa" were to be judged as "same". Letter pairs remained on the screen until the subject responded.

At variable intervals (65, 150, 250, 500 or 1000 msec) before the appearance of a letter pair, a warning signal or prime appeared on the CRT. This prime stayed on the screen until the letter pair appeared. The prime was displayed in a position above the middle of the letter pair. The purpose of the prime was to provide subjects with advance information, on some of the trials, as to the nature of the upcoming letter pair. On 50% of the trials the prime was a plus sign ("+") and did not convey any specific information. On the remaining 50% of the trials the warning signal was a single letter.

The nature of the information contained in the prime when it was a letter depended on whether the subject was in the "valid" or "invalid" prime conditions. In the valid condition the prime matched the letter array on 80% of the "same" trials and did not match on the remaining same trials. In the invalid condition the prime matched the array on only 20% of the "same" trials. Subjects in the valid condition were informed of the informative nature of the letter prime. Subjects in the invalid condition were only told that the warning signals, whether a plus sign or a letter, indicated that a letter pair was about to appear. The eight combinations of prime type and letter pairs that were used in this experiment are shown in Table 1.

Immediately following a response, the letter pair was wiped from the screen. It was replaced by feedback which informed the subject of his/her reaction time on that trial and whether or not the response had been correct. For example, if "-587" appeared, that indicated that the subject had taken 587 milliseconds to make an incorrect response; "684" would indicate a correct response which had been made in 684 milliseconds.

Table 1

Prime/array Types

Prime	Array	Response
+	Bb	same
+	Bg	different
+	BB	same
+	BG	different
A	AB	different
A	BG	different
A	AA	same
A	BB	same

The meaning of the feedback was explained to all subjects at the start of the experiment.

There were three blocks of 200 trials each. A rest period lasting about two minutes was given between blocks. Subjects were told, "We are interested in both how fast you are and how accurate you are so go as fast as you can while being as accurate as possible." A key board with two keys was in front of the subject. The left index finger was used to press the left key to indicate a "same" response while a "different" response was indicated by using the right index finger to press the right key. Presentation of stimuli and recording of responses was done by an on-line PDP-15 computer.

Results

Characteristics of the populations. The ages, sex breakdown, and educational levels along with scores on the three WAIS sub-tests for old and young subjects are given in Table 2. Aside, of course, from age, the two groups of subjects differed significantly only on vocabulary, with the older subjects scoring better on this test ($t = 3.00$, df = 43, $p < .005$).

Reaction time results. The overall reaction times and error rates for the four groups of subjects for each of the eight different prime/array combinations are shown in Table 3. Data from the first block of trials for each subject was considered practice and is not included in this analysis. A 2 X 2 X 8 analysis of variance (Age X Condition X Prime/array type) revealed a significant effect of age ($F[1, 41] = 20.27$, $p < .001$) with older subjects being slower than younger ones. The stimulus type also had a highly significant effect ($F[7, 287] = 104.47$, $p < .001$).

Table 2

Characteristics of the Subjects

	N	Age	Education	Digit span	Vocabulary	Block design
Old	28	63.5	14.5	6.2	62.2	33.9
Young	17	20.0	13.1	6.8	52.5	39.2

Table 3

Correct Reaction Times and Error Rates for Different

Subject Groups and Prime/Array Types

		Young valid		Young invalid		Old valid		Old invalid	
Prime	Pair	RT	% Error	RT	% Error	RT	% Error	RT	% Error
+	Bb	617	19	609	27	898	8	809	6
+	Bg	618	12	648	8	998	4	914	5
+	BB	510	8	514	3	717	1	665	1
+	BG	546	8	574	5	832	3	733	1
A	AB	523	8	567	6	849	3	732	2
A	BG	520	6	554	5	829	3	725	2
A	AA	452	1	498	3	689	1	658	1
A	BB	535	13	528	7	766	4	682	2

The age by stimulus type interaction was also significant (F[7, 287] = 8.60, $p < .001$). A two-way analysis of variance on the error rates (age by condition) revealed a significant effect of age (F[1, 41] = 14.51, $p < .001$), the older subjects being much more accurate than their younger counterparts.

Finally, although both the younger and the older subjects were generally faster on the third block than on the second, this practice effect was not significant for either group. Nor was the age by block interaction significant.

Figures 1 and 2 show the patterns of costs and benefits for the four groups of subjects. The cost function represents the <u>increase</u> in reaction time associated with an invalid, or misleading, letter prime at each of the five prime to array intervals. Specifically, cost is calculated as follows:

$$\text{COST} = \text{RT}\begin{pmatrix} & B & \\ A & & A \end{pmatrix} - \text{RT}\begin{pmatrix} & + & \\ A & & A \end{pmatrix}$$

A 2 X 2 X 5 analysis of variance on the cost data (Age X Condition X Duration) showed no effect of age, condition or duration. There was, however, a significant condition by duration interaction (F[4, 164] = 2.91, $p < .025$).

Benefit, on the other hand, represents the <u>decrease</u> in reaction time associated with a valid prime. Specifically:

$$\text{BENEFIT} = \text{RT}\begin{pmatrix} & + & \\ A & & A \end{pmatrix} - \text{RT}\begin{pmatrix} & A & \\ A & & A \end{pmatrix}$$

A 2 X 2 X 5 analysis of variance on the benefit data (Age X Condition X Duration) showed no effect of age. There were significant effects of both condition (F[1, 41] = 6.08, $p < .025$) and duration (F[4, 164] = 4.53, $p < .01$).

The use of same case and different case arrays permitted the examination of the differences between physical and phonetic (or name) matches. The node times are obtained by subtracting the reaction time for $B^{+}B$ stimuli from that for $B^{+}b$ stimuli. These node times for the young and the old subjects are shown in Table 4 along with error rates. The difference between young and old subjects is significant ($t = 3.41$, $df = 43$, $p < .005$).

Discussion

The paradigm used in the present study has the advantage of permitting the examination, within the same experiment and using the same subjects, of several hypotheses based on the different theoretical approaches to age-related slowing outlined above. First, the hypothesis that slowing is due to insufficient motivation to respond rapidly suggests that older subjects should be both slower and more accurate than younger ones. The results strongly support this hypothesis. Also supporting the view that motivational effects are responsible for age-related changes in speed of response is Salthouse's report (1975) that younger and older subjects are operating at different points along the speed/accuracy tradeoff curve. This is all not to say that older subjects are less motivated overall; rather they seem to be motivated toward a different goal (accuracy) than the young (speed).

The hypotheses that slowing with age is central rather than peripheral can be examined by comparing the differences between times for physical ("AA") and name ("Aa") matches for younger and older subjects. These "node times" do show an increase with age (Table 4), replicating Boies'

Table 4

Node Times

Age group	Node time (msec)	% Error
Young	101	17
Old	162	6

(1971) findings. However, again there seems to be a speed/accuracy trade-off operating with the younger subjects making almost three times as many errors as the older subjects. The present result is unlike that of Gaylord and Marsh (1975) who found that older subjects were both slower and made more errors on a mental rotation task.

The present study offers a method for separating automatic and attentional processes. This is achieved by analyzing the data for costs and benefits (Posner & Snyder, 1975a, b). Within this framework, cost is a measure of the time required for the subject to shift active attention to the prime following its appearance. The faster attention is directed to the prime, the larger the costs will be. Using this measure of attention, we find no significant difference between the young and the old subjects on either the amount or the time course of cost. However, differences are in the direction of larger costs for older subjects.

The benefit portion of the cost-benefit analysis offers a method for examining the time course of automatic pathway activation in the two groups of subjects. In previous work, an invalid prime led to benefit without any cost. This was taken as evidence supporting the automatic nature of benefit in the invalid condition. In the current experiment the invalid condition shows costs which are smaller both in reaction time and errors than in the valid condition. Thus one can argue that the invalid condition produces less attention to the cue than the valid condition. The failure to eliminate costs entirely in the invalid condition of this experiment may be due to the relatively few trials provided to subjects. To some extent benefit in the invalid condition can be used as a measure of pathway activation perhaps combined with some attentional effects.

There is no significant difference between old and young in the amount or the time course of benefit. The direction of the effect, however, is toward greater benefit in the young than the old.

The time course of costs and benefits are quite similar in the old and young (see Figures 1 and 2). The absolute size of benefits is greater in the young and size of costs is greater in the old. Neither of these effects is significant statistically, however. While the methods employed in this study seem useful in helping to delineate the locus of aging effects on automatic and attended processes, it must be confessed that the current data are not sufficient to be definitive on this score.

It remains to explain the older subjects' greater emphasis on accuracy. The reaction time feedback after each trial is a factor which may have contributed to the speed/accuracy differences found in the present study. Younger subjects may have made more use of reaction time feedback than did the older subjects. In fact, when questioned informally after the experimental sessions, older subjects tended to say that they had ignored the reaction time feedback. Younger subjects, on the other hand, indicated that they had used the feedback to pace themselves. To investigate this differential use of feedback by the two groups a second study was performed.

The design of the second study was identical to that of the first except that subjects were not provided with any feedback about their performance during the experimental session. None of the subjects in the second study, young or old, had participated in the first study. As in the first study, older subjects were slower and more accurate than the younger ones. However, in comparing the reaction times of the subjects in the first study, who received feedback, with the reaction times of

those in the second, who did not receive feedback (treating the presence or absence of feedback as a between subjects variable), a significant interaction between age and feedback conditions was found ($F[1, 75] = 4.61$, $p < .05$). Younger subjects who received feedback were faster and made more errors than the younger subjects who did not, but this was not true of older subjects. An analogous age by feedback condition interaction was found in the error data ($F[1, 75] = 7.24$, $p < .01$) with younger subjects who received feedback making more errors than those who did not.

The findings of the second experiment are in accord with a view that the younger subjects make more use of feedback information to pace themselves than do the older subjects.

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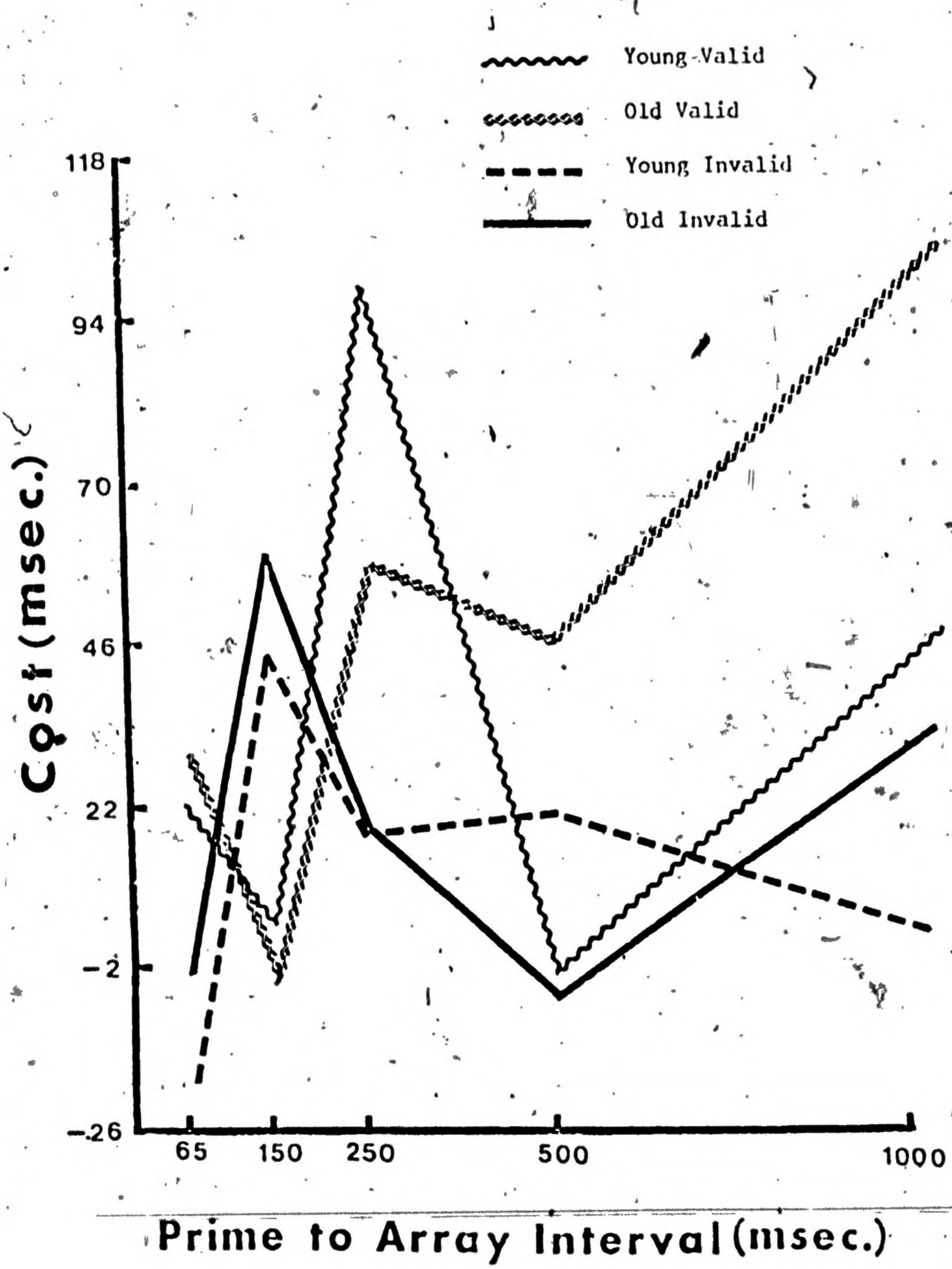
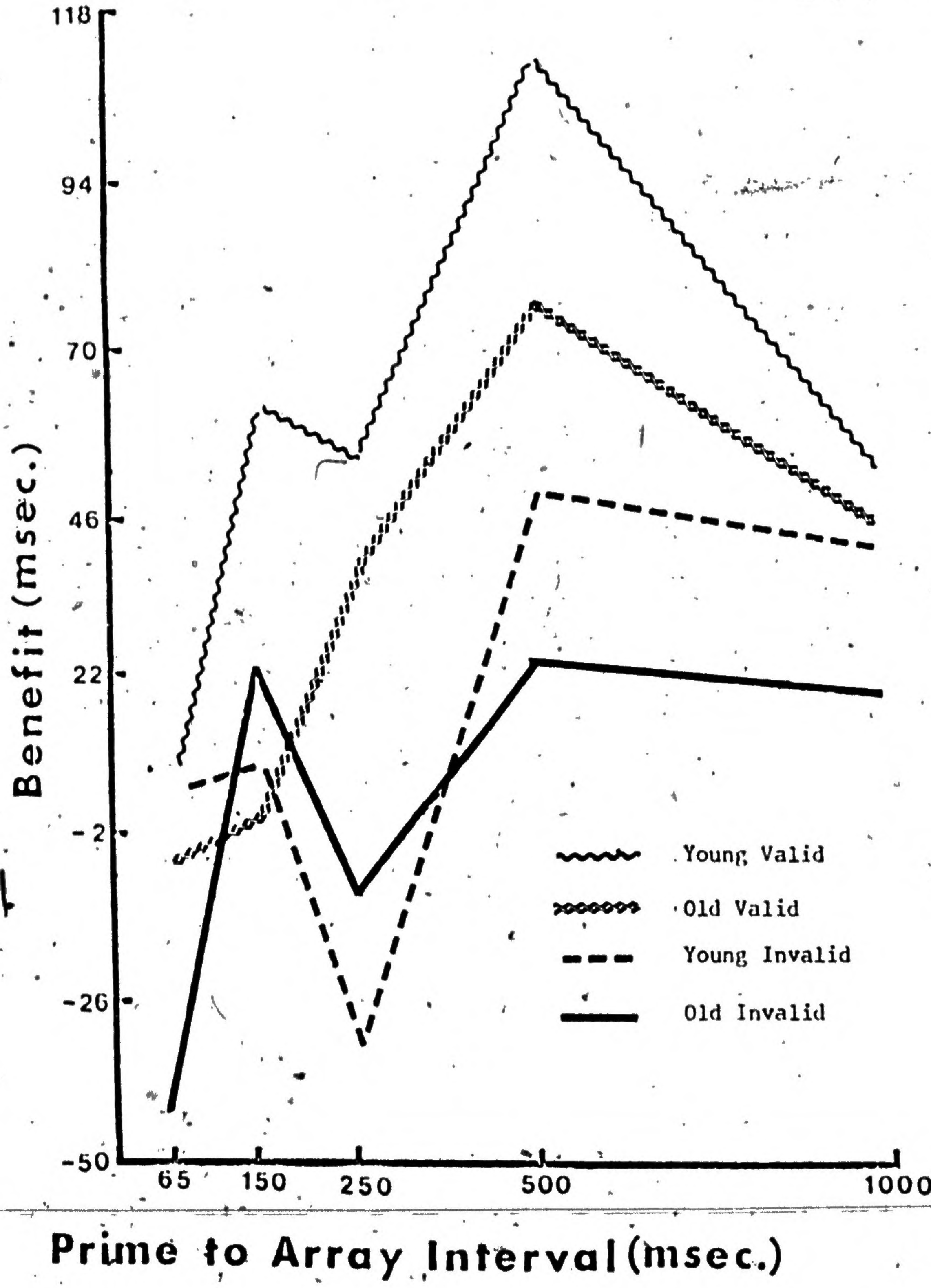
Figure 1



Young-Valid
Old Valid
Young Invalid
Old Invalid
118
94
70
46
22
-2
-26
Cost (msec.)
65
150
250
500
1000
Prime to Array Interval (msec.)

Figure 2



118
94
70
46
22
-2
-26
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Benefit (msec.)
65
150
250
500
1000
Prime to Array Interval (msec.)
Young Valid
Old Valid
Young Invalid
Old Invalid